

**Compendium of Methods
for the Determination of
Inorganic Compounds
in Ambient Air**

Compendium Method IO-1.2

**DETERMINATION OF PM₁₀
IN AMBIENT AIR USING
THE THERMO ENVIRONMENTAL
INSTRUMENTS (FORMERLY
WEDDING AND ASSOCIATES)
CONTINUOUS BETA
ATTENUATION MONITOR**

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Method IO-1.2

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Method IO-1.2
Determination of PM₁₀ in Ambient Air
Using the Thermo Environmental Instruments
(formerly Wedding) Continuous Beta Attenuation Monitor

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Chapter IO-1

CONTINUOUS MEASUREMENT OF SUSPENDED PARTICULATE MATTER (SPM) IN AMBIENT AIR

Method IO-1.2 DETERMINATION OF PM₁₀ IN AMBIENT AIR USING THE THERMO ENVIRONMENTAL INSTRUMENTS (FORMERLY WEDDING) CONTINUOUS BETA ATTENUATION MONITOR

1. Scope

1.1 The area of toxic air pollutants has been the subject of interest and concern for many years. Recently the use of receptor models has resolved the elemental composition of atmospheric aerosol into components related to emission sources. The assessment of human health impacts resulting in major decisions on control actions by federal, state and local governments is based on these data. Accurate measures of toxic air pollutants at trace levels are essential to proper assessment.

1.2 Suspended particulate matter (SPM) in air generally is a complex, multi-phase system of all airborne solid and low-vapor pressure liquid particles having aerodynamic particle sizes from below 0.01 μm to 100 μm and larger. Historically, SPM measurement has concentrated on total suspended particulates (TSP), with no preference to size selection.

1.3 The EPA reference method for TSP is codified at 40 CFR 50, Appendix B. This method uses a high-volume sampler to collect particles with aerodynamic diameters of approximately 100 μm or less. The high-volume samples 40 and 60 ft^3/min of air with the sampling rate held constant over the sampling period. The high-volume design causes the TSP to be deposited uniformly across the surface of a filter located downstream of the sampler inlet. The TSP high volume can be used to determine the average ambient TSP concentration over the sampling period, and the collected material subsequently can be analyzed to determine the identity and quantity of inorganic metals present in the TSP.

1.4 Research on the health effects of TSP in ambient air has focused increasingly on those particles that can be inhaled into the respiratory system, i.e., particles of aerodynamic diameters $< 10 \mu\text{m}$. Researchers generally recognize that these particles may cause significant, adverse health effects.

1.5 On July 1, 1987, the U. S. Environmental Protection Agency (EPA) promulgated a new size-specific air quality standard for ambient particulate matter. This new primary standard applies only to particles with aerodynamic diameters ≤ 10 micrometers (PM₁₀) and replaces the original standard for TSP.

1.6 To measure concentrations of these particles, the EPA also promulgated a new federal reference method (FRM). This method is based on the separation and removal of non-PM₁₀ particles from an air sample, followed by filtration and gravimetric analysis of PM₁₀ mass on the filter substrate. These smaller particles are able to reach the lower regions of the human respiratory tract and, thus, are responsible for most of the adverse health effects associated with suspended particulate pollution.

1.7 Monitoring methods for particulate matter are designated by the EPA as reference or equivalent methods under the provisions of 40 CFR Part 53, which was amended in 1987 to add specific requirements for PM₁₀ methods. Part 53 sets forth functional specifications and other requirements that reference and equivalent

methods for each criteria pollutant must meet, along with explicit test procedures by which candidate methods or samplers are to be tested against those specifications. General requirements and provisions for reference and equivalent methods are also given in Part 53, as are the requirements for submitting an application to the EPA for a reference or equivalent method determination.

1.8 Under the Part 53 requirements, *reference methods* for PM₁₀ must use the measurement principle and meet other specifications set forth in 40 CFR 50, Appendix J. They must also include a PM₁₀ sampler that meets the requirements specified in Subpart D of 40 CFR 53. Appendix J specifies a measurement principle based on extracting an air sample from the atmosphere with a powered sampler that incorporates inertial separation of the PM₁₀ size range particles followed by collection of the PM₁₀ particles on a filter over a 24-h period. The average PM₁₀ concentration for the sample period is determined by dividing the net weight gain of the filter over the sample period by the total volume of air sampled. Other specifications are prescribed in Appendix J for flow rate control and measurement, flow rate measurement device calibration, filter media characteristics and performance, filter conditioning before and after sampling, filter weighing, sampler operation, and correction of sample volume to the EPA reference temperature and pressure. In addition, sampler performance requirements in Subpart D of Part 53 include sampling effectiveness (the accuracy of the PM₁₀ particle size separation capability) at each of three wind speeds and "50% cutpoint" (the primary measure of 10-micron particle size separation). Field tests for sampling precision and flow rate stability are also specified. In spite of the instrumental nature of the sampler, this method is basically a manual procedure, and all designated reference methods for PM₁₀ are therefore defined as manual methods.

1.9 This document describes the protocol for the operation of a continuous particulate mass monitor that directly measures mass concentrations of atmospheric particulate matter as PM₁₀ on a real-time basis.

1.10 The instrument uses the beta gauge method, which is based on the attenuation of beta particles as they pass through the particulate matter that has been deposited on a filter.

1.11 With certain specifications, the instrument has been designated as an equivalent method for PM₁₀ (24-h average concentration) by the EPA under Designation No. EQPM-0391-081, effective March 5, 1991 (1). Except as otherwise noted, this protocol addresses the configuration and operation of the instrument as an equivalent method for PM₁₀.

2. Applicable Documents

2.1 ASTM Standards

- D1356 *Definitions of Terms Related to Atmospheric Sampling and Analysis*.

2.2 Other Documents

- Thermo Environmental Instruments Technical Manual (2).

3. Summary of Method

3.1 Particle-laden air is drawn through a sampling inlet at a constant volumetric flow rate of 18.9 L/min, the design flow rate for the Thermo Environmental Instruments (formerly Wedding and Associates) PM₁₀ inlet. The sample air stream passes downward through a filter tape collection substrate where the particles are deposited.

3.2 Upon completion of the sampling cycle, the filter tape is shifted to the beta source/detector to measure the attenuated count rate due to the presence of collected particles.

3.3 The silicon semiconductor beta detector has high sensitivity and fast response, enabling the instrument to measure the ambient mass concentration with a resolution of approximately 3 µg/m³ of collected particles for a 1-h sampling period.

3.4 The Thermo Critical Flow Device maintains a constant volumetric flow rate through the instrument.

3.5 A microcomputer-based data acquisition system controls the filter tape drive, monitors temperature and pressure, calculates flow rate and mass concentration values, and provides the necessary analog outputs for a telemetry system. Custom system software can be provided by Thermo to assist the users to meet the particular, unique requirements of their application.

[Note: The PM₁₀ concentrations calculated by the original instrument are in terms of µg per actual m³. These values must be converted by the user into µg per standard m³. Instruments modified with a manufacturer-provided retro-fit kit (described later) report concentrations in either µg per actual or standard m³.]

4. Significance

4.1 SPM in air generally is a complex, multi-phase system of aerodynamic particle sizes from below 0.01 μm to greater than 100 μm . Historically, SPM measurement has concentrated on TSP, with no preference to size selection. Research on the health effects of TSP in ambient air has focused increasingly on those particles that can be inhaled into the respiratory system (i.e., particles of aerodynamic diameter less than 10 μm [PM₁₀]). Researchers generally recognize that those particles may cause significant adverse health effects.

4.2 Because of the health effects of PM₁₀, this continuous particulate monitor has been developed to allow mass measurement of PM₁₀ concentration on a quasi, real-time basis.

4.3 The monitor utilizes a filter-based measuring system for providing quasi, real-time mass monitoring capability. The particulate matter sample is retained on the filter tape. With certain specifications, the monitor has been designated by EPA as an equivalent method for determining the 24-h average ambient concentration of PM₁₀. In addition, the instrument can be operated outside the equivalent method specifications to perform other types of PM sampling programs.

5. Definitions

[Note: Definitions used in this method are consistent with the definitions found in ASTM D1356. All abbreviations and symbols are defined within this document at the point of first use. Any user prepared standard operating procedures (SOPs) should also conform to the definitions of ASTM D1356.]

5.1 Air pollution. The presence of unwanted material in the air. The term "unwanted material" here refers to material in sufficient concentrations, present for a sufficient time, and under circumstances to interfere significantly with comfort, health, or welfare or persons or with the full use and enjoyment of property.

5.2 Beta particle. An elementary particle emitted by radioactive decay, that may cause skin burns.

5.3 Coarse and fine particles. Coarse particles and those with diameters (aerodynamic) greater than 2.5 μm that are removed by the sampler's inlet; fine particles are those with diameters (aerodynamic) less than 2.5 μm . These two fractions are usually defined in terms of the separation diameter of a sampler.

5.4 Filter. A porous medium for collecting particulate matter.

5.5 Mass concentration. Concentration expressed in terms of mass of substance per unit volume of gas.

5.6 Particle. A small discrete mass of solid or liquid matter.

5.7 Particle concentration. Concentration expressed in terms of number of particles per unit volume of air or other gas.

[Note: On expressing particle concentration the method of determining the concentration should be stated.]

5.8 Sampling. A process consisting of the withdrawal or isolation of a fractional part of a whole. In air or gas analysis, the separation of a portion of an ambient atmosphere with or without the simultaneous isolation of selected components.

5.9 Sampling, continuous. Sampling without interruptions throughout an operation or for a predetermined time.

6. Interferences

6.1 Because the measurement mechanism has no moving parts, the instrument is not sensitive to vibrations (e.g., vacuum pump vibration or mechanical noise) that can affect the accuracy of some other types of continuous PM monitors.

6.2 Unlike some types of continuous PM monitors, this instrument does not require the ambient air stream to be heated to a particular standard temperature. This feature eliminates a potential source of inaccuracy; heating can volatilize some semivolatile materials that would otherwise be deposited on the filter, leading to inaccuracies in both mass measurements and later chemical analyses.

6.3 The instrument should be protected against condensation in the sampling system, which can affect the accuracy of the mass measurements.

7. Apparatus

The instrument includes two custom cabinets, one for PM sampling and control and one for the vacuum pump. The insulated main particle sampling cabinet (shown in Figure 1) is heated and cooled so that it can operate under ambient conditions. However, the instrument should be housed in a heated and air conditioned shelter. The heating and cooling are independently controlled to preclude temperature extremes within the cabinet.

After assembly, the inlet tube extends upward from the main sampling cabinet and is topped by the PM₁₀ Inlet (see Figure 2). The front cabinet door opens to reveal the filter reels, LCD define display, particle sampling module, the source/detector fixture, communication ports, keypad, and printer, as shown in Figure 1. Newer units are not equipped with a printer because users typically connect the unit to a data logger or computer for data storage and access. Figure 3 illustrates the back of the cabinet, where the main power cord enters and the power supply cord and vacuum tubing that lead to the vacuum pump emerge.

A modification kit, available from the manufacturer, includes new temperature sensors, new software contained on a new EPROM chip, a calibration foil, installation instructions, and a manual supplement, and provides improved accuracy of flow measurement and other features.

The vacuum pump cabinet contains a separate cooling fan that is activated when the pump operates. As illustrated in Figure 3, the vacuum sampling tube is connected from a fitting on the pump cabinet to a fitting on the particle sampling cabinet. The power to the pump cabinet also comes from the main cabinet. The major components of the instrument are described below.

7.1 Sampler PM₁₀ Inlet

A modified Thermo inlet, originally developed for the dichotomous sampler, is used as the sampling inlet for the PM₁₀ beta gauge. The inlet achieves proper particle size separation at a sampling rate of 16.7 L/min, the design flow rate of the instrument. TSP and PM_{2.5} inlets are also available from the manufacturer.

The PM₁₀ sampling inlet is illustrated in Figure 4. The inlet employs an omnidirectional cyclone fractionator, which allows the particles to enter from any angle of approach. An angular impetus is imparted to the particle motion via the eight, evenly-spaced entrance vanes. As the particles enter the inlet, they follow the fluid stream lines along the lower radius and enter the cyclone fractionator through the vane system. Particle removal is realized on the oiled surfaces of the inner collection tube. The transmitted particles then enter the middle tube, where the flow direction is altered 180°. A final turn is made giving the particles a downward trajectory to the collection substrate.

7.2 Analog Board

The analog board consists of the various circuits used for supplying DC power, motor control, relaying, temperature sensing, and signal conditioning needs for the instrument. Most of the wiring for the instrument is provided by the analog board.

7.3 Micro-Controller Board

The micro-controller board provides operational controls, time and flow-rate data recording, and all data calculations and conversions.

7.4 Tape Drive and Sampling Module

The instrument uses a bi-directional tape drive system. First, a background beta count is taken on the area of the filter tape that is situated in the measurement position (i.e., between the beta source and the detector). When the background count is completed, the particle sampling module opens, the tape advances, and the filter spot on which the background count was taken is positioned beneath the sample inlet tube. The particle sampling module then closes and seals, and sampling is initiated by starting the vacuum pump. After the 1-h sampling cycle is completed, the sampling module opens, the filter tape with deposited PM₁₀ is shifted back to the measurement position, the sample module closes, and a beta count is taken. Mass concentration is determined based on the mass of PM₁₀ accumulated and the volumetric flow rate of the instrument during the sampling cycle.

The standard instrument is programmed to repeat the sampling and measurement cycle four times on a single spot before the filter tape advances to an unused spot. Thus, total sampling time on each spot is 4 h. The instrument also is programmed to go to a shorter cycle if PM₁₀ is accumulating so fast that the flow rate will be reduced to an unacceptable level in less than 4 h. The manufacturer can supply software for different sampling cycles, but the current model of the instrument does not allow the user to select the sampling cycle.

7.5 Filter Media

Thermo offers two choices of filter substrates--glass fiber (P/N BG-320) and membrane (P/N BG-310). The instrument is designated as an equivalent method for PM₁₀ using the glass fiber filter medium. This filter medium can accumulate extremely high PM loadings without incurring a significant increase in pressure drop across the filter. The membrane medium is made of Teflon®, and is not affected by moisture.

The filter medium is supplied as a tape on a reel. The tape is threaded from the supply reel, through the measurement and sampling positions, to the takeup reel. Instructions for replacing the filter tape are presented in Section 11.

7.6 Radioactive Source

A carbon-14 radioactive source is mounted into the fixture positioned beneath the filter tape. In no case should the front (top) surface of the source or source fixture be touched. Should the source laminate become scratched, the radioactive material may leak. A damaged source must be returned to Thermo for disposal and replacement. The radioactive source has the following characteristics: (1) an isotope of ¹⁴C, (2) an activity of < 100 μCi, (3) a half-life of 5,730 yr, (4) a maximum energy of 155KeV, and (5) a laminate-sealed housing. In addition, this source is described as a Thermo 1186 Series ¹⁴C Source.

The long half-life of carbon-14 precludes the need for recalibration and replacement of the source. The use of the fast-response, low noise semiconductor detector makes it possible to use a low activity, low energy beta source. Carbon-14 also has the added advantage of being a pure beta emitter without residual gamma radiation.

The radioactive labels, positioned on the side of the cabinet, clearly provide instructions to the user for disposition of the device and by-product material if necessary. At no time should the labels be removed. See Section 14 for a discussion of safety considerations.

7.7 Detector Assembly

An ion-implanted silicon semi-conductor (IISS) detector and a preamplifier acquisition board (PACB) are packaged in one fixture. The IISS detector is used to stop beta particles and permit counting of particles that penetrate the filter medium. The IISS detector accepts an exceptionally high incidence of beta, having a maximum count-rate of 100,000 cps, possesses ultra low-noise characteristics, and is a ruggedly designed. The detector is optimized individually for each unit to stop beta particles emitted from the carbon-14 source. The IISS detector has low leakage current (1-10 nA/cm²/100 μm), which makes it well suited for measuring low-energy beta particles.

7.8 Data Output Devices

[Note: The instrument does not store measurement or calculation data. The user must provide a suitable data handling system to maintain a record of measured and calculated parameters.]

7.8.1 Parallel Printer. Older units are equipped with a built-in parallel printer, but the units now being shipped do not have this feature. When activated, this printer records all measurements and calculated values generated by the instrument. However, this printer should not be operated when the instrument is unattended because the printer paper can interfere with the filter tape drive mechanism.

7.8.2 Telemetry (Analog) Output. The instrument provides up to six channels of 0-5 volts direct current (VDC) output for use with telemetry applications (two channels are standard). These data channels are available through a 25-pin connector located on the main instrument panel.

7.8.3 RS-232 (Digital) Output. A second 25-pin connector on the main instrument panel serves as the connection point for a serial printer or digital communications device, such as a data logger or computer. In communications mode, this port can be used for remote control over the instrument.

7.9 Critical Flow Device

The collection of accurate and meaningful PM₁₀ or TSP concentrations is intimately related to proper flow control. Flow control provides an accurate denominator for the calculation of mass concentrations, whether PM₁₀ or TSP is being measured, and maintains the design flow rate of the PM₁₀ fractionating element so that it operates at the specific air velocities for which it was intended.

The Critical Flow Device (CFD), a critical flow system requiring no periodic calibration, is used as a flow control device for the instrument. Use of the CFD provides for accurate flow rate measurement. The critical flow orifice within the CFD is sized specifically for use with only one type of filter medium (i.e., either glass fiber or Teflon®) to provide the flow rate necessary for proper particle size selection by the PM₁₀ inlet. Each instrument is calibrated at the factory, and an instrument-specific flow coefficient constant is supplied with each unit for accurately calculating the flow rate during operation. This constant is entered into the instrument's battery-backed random access memory (RAM) at the factory and duplicated on a label affixed to the instrument panel. In the event of battery failure, the user must re-enter the constant into RAM (see Section 10.3.1).

Caution: Use of a filter medium other than that originally specified for the instrument may result in a flow rate different from that for which the PM₁₀ inlet is designed.

The flow rate through the filter tape is continuously monitored during operation by the micro-controller board. Atmospheric pressure is measured with an electronic pressure transducer when the pump is off between sampling periods. The stagnation pressure (i.e., the absolute pressure downstream from the filter medium) is measured while the vacuum pump is operating during the sampling cycle. The microcomputer outputs the flow rate and the average values of temperature and pressure for the sampling period.

A modification kit, which is available from the manufacturer and is highly recommended, provides a temperature sensor to measure ambient (outdoor) temperature to allow the instrument to more accurately calculate the actual volumetric flow rate at the sample air inlet. This modification also allows the instrument to report flow rates in either actual or standard volume units and likewise calculate mass concentrations in either µg per actual or EPA-standard cubic meters.

7.10 Vacuum Pump

The vacuum pump cabinet houses a Gast Model #523-101Q-G18DX or G21DX vacuum pump for power supplies of 115 volts alternating current (VAC)/60 Hertz (Hz) or 220-240 VAC/50 Hz, respectively. A cooling fan is activated when the pump operates. The pump is connected to the main sampling cabinet with a vacuum tube supplied by the manufacturer. Power to the pump cabinet comes from the main cabinet.

8. Assembly

8.1 The instrument is delivered on a pallet protected by foam packaging and a cardboard outer container. Remove the instrument from the packaging by cutting the metal bands on the outside of the container. Save the container in the event that the instrument needs to be transported or repackaged.

8.2 After removing the metal bands and opening the cardboard container, locate and remove the instrument components from the foam packing material. The separate pieces are as follows: main sampling cabinet,

pump cabinet, inlet, inlet tube, inlet tube support ring, cleaning brush, cabinet keys, and manual. (The inlet tube support ring, cleaning brush, and keys should be in a plastic bag.)

8.3 Once all components have been located and removed from the box, assemble the instrument. First, insert the inlet onto the end of the inlet tube (it will only fit on one end of tube).

8.4 If the instrument is to be operated with either an extension to the inlet tube or under ambient conditions where high winds may be encountered, install the support ring onto the inlet tube. Slide the support ring onto the inlet tube and tighten the four screws. Do not overtighten the screws or indentations in the tube could be run and, thus, alter the air flow. Attach guide or support wires to the heads of the four screws. If a nonstandard inlet tube (such as an extension) is to be used, contact Thermo for guidance.

8.5 Insert the inlet tube into the main cabinet of the instrument. Use extreme caution because forcing the tube into the cabinet could damage the instrument. Rotate the tube and push it carefully into the cabinet to avoid damaging the O-rings inside the coupler. The tube is fully inserted when resistance from the coupler is felt. When assembled with the standard inlet tube, the inlet is at a height of about 2 meters above the base of the main cabinet.

8.6 Insert the key into the rear door of the main cabinet and rotate the key counterclockwise until the door opens. Check all electrical connections. Make sure there are no loose or unattached cables.

8.7 Instruments sold before November, 1996 should be modified with the modification kit provided by Thermo. Install the kit according to instructions provided by Thermo. The kit provides new temperature sensors and electronics for improved accuracy of flow measurements, enabling reporting of concentration in either μg per actual or EPA-standard cubic meters.

8.8 Attach the vacuum pump to the main cabinet with the Tygon® tubing inside the vacuum pump cabinet. This step requires a 9/16" open end wrench or adjustable wrench to tighten the bulkhead fittings.

8.9 Plug the pump cabinet power cord (male) into the power supply cord (female) extending from the rear of the main cabinet.

8.10 Open the door of the main cabinet that houses the instrument panel. First, make sure that the power switch at the top of the instrument panel is in the "OFF" position. Then supply power to the unit (115 VAC/60 Hz or 220 VAC/50 Hz) through the power-in cord (male) located on the rear door of the cabinet. The instrument is now ready for start-up and operation.

9. Siting Requirements

9.1 As with any type of air monitoring study in which sample data are used to draw conclusions about a general population, the validity of the conclusions depends on the representativeness of the sample data. Therefore, the primary goal of a monitoring project is to select a site or sites where the collected particulate mass is representative of the monitored area.

9.2 Basic siting criteria for the placement of ambient air samplers are documented in Table 1. This list is not a complete listing of siting requirements; instead, an outline to be used by the operating agency to determine a sampler's optimum location. Complete siting criteria are presented in 40 CFR 58, Appendix E.

9.3 Additional factors not specified in the Code of Federal Regulations (CFR) must be considered in determining where the sampler will be deployed. These factors include accessibility under all weather conditions, availability of adequate electricity, and security of the monitoring personnel and equipment. The sampler must be situated where the operator can reach it safely despite adverse weather conditions. If the sampler is located on a rooftop, care should be taken that the operator's personal safety is not jeopardized by a slippery roof surface during inclement weather. Consideration also should be given to the fact that routine operation (i.e., calibrations, filter installation and recovery, flow checks and audits) involves transporting supplies and equipment to and from the monitoring site.

9.4 To ensure that adequate power is available, consult the manufacturer's instruction manual for the sampler's minimum voltage and power requirements. Lack of stable power source can result in the loss of many samples because of power interruptions.

9.5 The security of the sampler itself depends mostly on its location. Rooftop sites with locked access and ground-level sites with fences are common. In all cases, the security of the operating personnel as well as the sampler should be considered.

10. Instrument Operation

The instrument is operated with the keypad located in the main particle sampling cabinet (see Figure 1). Records of stored data can be obtained from the unit using the built-in 20-column parallel printer (when so equipped), the RS-232 communications port, or the telemetry port. When activated, the 20-column parallel printer, which is part of the instrument, provides a continuous printout of all sampling data. If needed, the RS-232 port is used to communicate with a separate computer. The telemetry port (labeled Analog Port on the instrument) provides the necessary signals to send data to an off-site source via telemetry.

10.1 Instrument Start-up

To begin operation, move the power ON/OFF rocker switch at the top of the instrument panel to the "ON" position (the red light should be on). The LCD will show several messages followed by the "PRESS A KEY" prompt. The valid control keys are shown in Figure 5, and a brief summary of each key, including the location and function, is shown in Table 2.

10.2 Loading the Filter Tape

Caution: NEVER turn the take-up (right side) tape drive manually, or the drive system will be damaged.

The filter tape drive system is illustrated in Figure 6. The filter substrate is a continuous tape. The tape lifetime is based upon the total number of samples and the ambient concentration levels. A reel of glass fiber tape lasts approximately 8 months using the standard sampling cycle.

10.2.1 The tape replacement commands are accessed from the keypad, but the loading procedure must be followed as written in this section. Press the key titled "LOAD TAPE." The following message is displayed:

**LOAD NEW TAPE
OPENING SYSTEMS**

After the instrument has performed the necessary mechanical functions for the loading of a new filter tape reel, the following message is displayed:

**LOAD NEW TAPE
OPENING SYSTEMS
REFER TO MANUAL &
PRESS A KEY TO LOAD**

10.2.2 Install an empty take-up reel on the right tape drive. First, remove the black plastic pronged knob from the right tape drive. Place the empty reel on the right tape drive, being sure to slide the hub onto the shaft so that the shaft pin fits into the slot on the hub. Replace the black knob and tighten snugly.

Caution: Tighten the knob and hold the reel at the same time. Do not apply excessive torque to the drive shaft, or the motor may be damaged.

10.2.3 Place a new filter supply reel on the left tape drive, ensuring that the pin on the shaft fits snugly into the slot on the black hub of the reel. (Note that these slots and pins define the vertical plane of the tape. The drive system will malfunction if the pins are not secured in the slots.) Replace the black knob.

10.2.4 Unwind about 24" (60 centimeters) of filter tape by rotating the supply side (left tape drive) in a counterclockwise direction. Feed the free end of the tape over the left side of the No. 1 transnational roller, as illustrated in Figure 6. Pass the free end of the tape, from left to right, between the No. 1 upper compression shaft and No. 1 lower compression roller, through the detector/sampling module and between the No. 2 upper compression shaft and the No. 2 lower compression roller. Continue by passing the tape on the right side of the No. 2 transnational roller. Wrap the tape in a counterclockwise fashion on the hub of the right (take-up) reel.

10.2.5 Tape the free end to the center of the take-up hub. Be sure that the filter tape is parallel to the edges of the reels. The tape must be in the same vertical plane along its entire path.

[Note: Be sure that the tape passes approximately in the center of all rollers and the sampling module so the tape is centered as it passes through the source, detector, inlet, and both (supply and take-up) reels.]

10.2.6 Depress any key to start the tape advancement, which is pre-programmed to operate for a specific time period (about 1 min). When the tape advancement is complete, ensure that the tape is properly positioned approximately in the center of both the No. 1 and No. 2 transnational rollers, that the tape is smooth and flat against each roller, and that it lies in the same vertical plane between supply and take-up reel. Additionally, the tape should be perfectly aligned between the upper compression shafts and the lower compression rollers and should be in the center of the detector/sampling module.

10.3 Setting Up the Instrument

10.3.1 The "C" key is used to set the calibration constant in battery-backed RAM in case it has been lost through battery failure. The five-digit constant, which is unique to each unit, is supplied by W&A and displayed on a label between the filter reels. To set the calibration constant, press the "C" key and input the five-digit constant as given on the label. After entering the fifth digit, the prompt "CHANGE (Y/N)?" will

appear on the LCD. If the constant is incorrect, restart the procedure by pressing the "YES" key. If the constant is correct, press the "NO" key. The "PRESS A KEY" prompt will return to the screen. (This step is not necessary for instruments equipped with the CFCASF flow controller.)

10.3.2 The "D" key is used to set the expected maximum mass concentration for the sampling site in battery-backed RAM. This five-digit constant contains no decimal point, and five digits must be entered. For example, if the maximum anticipated concentration is 250 µg/m³, the input constant is 00250. To set the constant, press the "D" key and enter the five-digit constant. After entering the fifth digit, the prompt "CHANGE (Y/N)?" will appear on the LCD. If the constant is incorrect, restart the procedure by pressing the "YES" key. If the constant is correct, press the "NO" key. The "PRESS A KEY" prompt will return to the screen.

[Note: Do not set an upper limit that is arbitrarily high because this will reduce the resolution of the telemetry (analog) output.]

10.3.3 The "SETUP" key is used to enter the correct date and time into the computer. When the "SETUP" key is pressed, the date and time will appear on the LCD followed by the prompt "CHANGE? (Y/N)". If the displayed date and time are incorrect, press the "YES" key. The prompt "INPUT DATE" will appear on the LCD. Enter the six-digit date with zeros preceding single digit days or months. Following the input of the date, the prompt "INPUT TIME" will appear on the LCD. Enter the six-digit time (hours, minutes, and seconds) based on a 24-h clock; the new date, time, and the prompt "CHANGE? (Y/N)" will appear on the LCD. When the correct date and time are displayed, press the "NO" key to complete the setup operation.

10.3.4 Press the "PROGRAM SAMPLING SCHEDULE" key to program the time at which the instrument is to begin a sampling cycle. The programmed date and time will appear on the LCD, followed by the prompt "CHANGE? (Y/N)". If the displayed date and time are incorrect, press the "YES" key. The prompt "INPUT START DATE" will appear on the LCD. Enter the six-digit start date, with zeros preceding single digit days or months; the prompt "INPUT START TIME" will appear on the LCD. Enter the six-digit start time (hours, minutes, and seconds) based on a 24-h clock; the prompt "PRESS A KEY" will appear on the LCD.

[Note: The input start time must be at least 15 min later than the actual time as indicated by the real-time clock.]

10.3.5 Verify that the "FLOW TEMP CORR" is ON (modified units) and select "STAN COND=ON" if flow and concentration are desired in standard volume units.

10.3.6 Press the "PARALLEL PRINTER ON/OFF" key to enable or disable the parallel printer (if so equipped). One of two messages will appear: "PARALLEL PRINTER ON" or "PARALLEL PRINTER OFF." To change the printer mode, press the "PARALLEL PRINTER ON/OFF" key again. If the unit is left unattended, the built-in parallel printer should be in the off mode because the paper may interfere with the mechanical movements.

10.3.7 The "RS-232 PRINTER ON/OFF" key operates in the same manner as the "PARALLEL PRINTER ON/OFF" key described above. A serial printer cannot be enabled at the same time the RS-232 communication port is on. (Only one device, a serial printer or a communications device, can be connected to the RS-232 port on the instrument panel.)

10.3.8 Press the "RS-232 COMM ON/OFF" key to enable or disable the communication port that provides the necessary signals to transmit data off-site. One of the following two messages will appear on the LCD. (1) If the communication port was in the off mode, the current baud rate is displayed followed by the prompt "CHANGE? (Y/N)". To change the baud rate, press the "YES" key and select a baud rate using

the numbered key that corresponds to the desired baud rate shown on the LCD. To accept the baud rate, press the "NO" key; the message "COMM. PORT ON" will appear on the LCD. (2) If the communication port was in the on mode, the message "COMM PORT OFF" will appear on the LCD. This communication port cannot be enabled at the same time the RS-232 serial printer is on.

10.4 Commencing Sampling

10.4.1 To check the instrument prior to commencing sampling, press the "TROUBLE SHOOT" key to initiate a series of 13 diagnostic tests. The results of each test will appear on the LCD with a "PASS" or "FAIL" message. The following four LCD messages illustrate all 13 tests and their results.

1) MODULE DN	PASS
2) COMP. UP	PASS
3) ADVANCE	PASS
4) COMP. DN.	PASS
5) TRANS. RT.	PASS
6) TRANS. LT	PASS
7) MODULE UP	PASS
8) PRESSURE	PASS
9) BETA CNT.	PASS
10) FLOWRATE	PASS
11) PS15	PASS
12) PS12	PASS
13) PS5	PASS

If a "FAIL" indication is displayed for any of the tests, make sure that all sampling information was entered correctly. Also, check the instrument for loose cables or other obvious problems (e.g., make sure the filter tape has been loaded). Press the "TROUBLE SHOOT" key again, and if the "FAIL" message still appears, contact the manufacturer for further service information.

10.4.2 Press the "STATUS" key to confirm the status (on/off) of the parallel printer port, serial printer port, and communications port. Press this key twice to confirm the actual status of these ports. If the status is not as desired, use the appropriate keys as described in Sections 10.3.5 through 10.3.7 to enable the desired output device(s).

[Note: The RS-232 serial printer and RS-232 communications cannot be on at the same time.]

10.4.3 Press the "BEGIN SAMPLING" key to begin sampling operations. The LCD will show the messages "INITIALIZING SYSTEM" and "PLEASE STANDBY" while the unit undergoes the necessary mechanical movements and checking procedures to permit the system to begin operation. When initialization is finished, the LCD shows the actual date and time, the sampling period, the mass concentration of the previous sampling period, and the message "A OR B TO TERMINATE." (All other control keys are disabled.) To immediately terminate sampling, press the "B" key. To terminate sampling at the end of the sampling period (approximately at the end of each hour), press the "A" key; the prompt "PRESS A KEY" will appear on the LCD. At this time, all valid control keys are enabled.

10.5 Other Control Keys

These keys are enabled only when the instrument is not in sampling mode.

10.5.1 A description of the "LOAD TAPE" key, which is used when loading a new filter tape, is provided in Section 10.2.1.

10.5.2 Press the "RESET" key to reinitialize the instrument. The LCD messages and prompts will be the same as when the instrument was turned on.

10.5.3 Press the "MODULE UP/DOWN" key to activate the sampling module motor. The sampling manifold will open and must be closed by pressing the "MODULE UP/DOWN" key again.

10.5.4 Press the "COMP UP/DOWN" key to activate the compression rollers. The compression rollers will open and must be closed by pressing the "COMP UP/DOWN" key again.

10.5.5 Press the "TRANS LEFT/RIGHT" key to translate the tape left or right. Following the first translation from left to right (i.e., from the measurement position to the sampling position), the message "ROLLERS MUST BE TRANSLATED LEFT TO EXIT" will be displayed. Press the "TRANS LEFT/RIGHT" key again to move the translation mechanism back to the original position (i.e., from the sampling position back to the measurement position).

10.5.6 Press the "VACUUM PUMP ON/OFF" key to test the vacuum pump. This action turns the vacuum pump on, and the message "VACUUM PUMP MUST BE TURNED OFF TO EXIT" will be displayed. Press the key again to turn the vacuum pump off.

Note: This key is only for testing the vacuum pump. Turn off the pump after testing for proper automatic operation of the instrument.]

10.5.7 Press the "ADVANCE TAPE" key to advance the filter tape one position. The message "ADVANCING" will be displayed on the LCD as the necessary operations take place. The operation may take up to 2 min because it requires the sampling module and compression rollers to be opened before the tape is advanced.

10.5.8 Press the "TEMP/PRESSURE" key to display the current cabinet temperature and atmospheric pressure.

10.5.9 Press the "BETA COUNT" key to determine if the beta count is acceptable. After a period of time, the message "COUNT ACCEPTABLE" or "COUNT UNACCEPTABLE" will appear on the LCD. If the "COUNT UNACCEPTABLE" message is displayed, make sure that all sampling information was entered correctly. Also, check the instrument for loose cables or other obvious problems. If the beta count remains unacceptable, fill out the troubleshoot questionnaire provided in Addendum 1 of the operating manual and contact the manufacturer for further service information.

10.5.10 Press the "FLOWRATE" key to display the actual flow rate of air through the instrument in cm³/min. If the displayed flow rate is unacceptable (off by more than 10% of the design flow rate of 16,700 cm³/min), make sure that all sampling information was entered correctly. Also, check the instrument for loose cables or other obvious problems such as obstructions in the inlet tube or system vacuum tubing. If the flow rate remains unacceptable, fill out the troubleshoot questionnaire provided in Addendum 1 of the operating manual, follow the procedures outlined in Section 14.3 of the operation manual (flow rate audit procedure), and contact the manufacturer for further service information.

11. Replacing the Filter Tape

Caution: NEVER turn the take-up (right side) tape drive manually, or the drive system will be damaged. The filter tape drive system is illustrated in Figure 6.

11.1 Press the "LOAD TAPE" key. The functioning of this key is described in Section 10.2.1.

11.2 Remove the full take-up reel from the tape drive on the right. Hold the reel firmly to keep it from rotating, loosen the black plastic pronged knob, and slide the reel off the shaft.

11.3 Move the previous supply reel (now empty) from the left tape drive to the right drive. First, loosen the black plastic pronged knob. Next, remove the reel and place it on the now-vacant right tape drive. Be sure to slide the hub onto the shaft so that the shaft pin fits into the slot on the hub. Replace the black knob and tighten snugly.

Caution: Tighten the knob and hold the reel at the same time. Do not apply excessive torque to the drive shaft or the motor may be damaged.

11.4 Complete the tape replacement by following the steps described in Sections 10.2.3 through 10.2.6.

12. Printer Paper Replacement (if applicable)

In instruments with a built-in printer, a full roll of paper is initially supplied with the parallel printer. The printer system is illustrated in Figure 7.

12.1 To replace an empty roll, gently press the printer faceplate latches and pull to remove.

12.2 Locate the metal tab adjacent to the paper sensor (LED), press it, and gently slide the printer out until it stops.

12.3 Remove the old roller and insert a fresh roll of printer paper. The printing surface of the paper is on the outside of the roll. Make certain the roll turns in a counterclockwise direction (referenced from the paper access area) as the paper unrolls.

12.4 Locate the paper slot in front of the small white roller at the bottom of the printer. Insert or feed the paper into the slot, pressing the feed switch until the paper comes out the printer head.

12.5 Gently slide the printer back into the housing and replace the faceplate.

13. Maintenance

The instrument is specifically designed to require minimal maintenance by the user. Four principal areas require attention. Two of these, replacing the filter tape and replacing the parallel printer paper, are discussed in Sections 11 and 12, respectively. Maintenance of the detector and sampling inlet are discussed below.

13.1 Detector

In general, the IISS detector should not be disturbed or removed from its mounting. If testing indicates that the detector surface is contaminated, the surface of the detector may be cleaned, very carefully, by using a suitable cleaning agent supplied by the manufacturer.

Caution: The sensitive area of the detector is delicate and should never be touched, except very lightly with a soft cotton swab.

13.2 Sampling Inlet

After operating for an extended period of time under high mass concentration conditions, the sampling inlet must undergo periodic maintenance. The maintenance procedure is a simple brushing technique to remove accumulated PM from the primary deposition area in the inlet.

Remove the maintenance access port and run the supplied cleaning brush down through the inner tube three times, twisting the handle between the fingers to insure that the brush touches all surfaces. This procedure should be repeated once after every 15 days of sampling operations.

14. Instrument Calibration

The instrument calibration may be checked and changed, if necessary, by the user. This section describes the initial calibration procedures used by the manufacturer for the instrument as well as field audit procedures for the user.

14.1 Mass Determination

14.1.1 The Thermo Beta Gauge system undergoes a complete calibration using aerosol standards in the laboratory. The laboratory calibration involves the generation of monodisperse solid particles injected into the Thermo Wind Tunnel Facility. The concentration level in the facility can be adjusted over the range of 25 to 300 Fg/m³. The calibration procedure is performed to determine the attenuation coefficient, which is used in the instrument's internal calculations to determine the mass of PM₁₀ collected on the filter.

In the calibration procedure, parallel samples of the particle cloud are collected using identical PM₁₀ inlets. One sample is collected using an appropriate filter substrate and subsequently analyzed fluorometrically to determine mass concentration. This mass concentration is then used to calculate mass density of particles on the filter tape. The second sample is analyzed using the Thermo Beta Gauge.

The procedure is repeated for a range of particle loadings. The beta attenuation values from the beta gauge are then related to the mass density levels determined from the first sampler. The attenuation coefficient for the beta gauge system is determined by a least-squares fit to a straight line on a plot of the various mass density values vs. corresponding attenuation values.

14.1.2 The manufacturer has performed this calibration procedure to determine generally-applicable attenuation coefficients for instruments that use glass fiber and membrane filter media (the attenuation coefficient differs slightly depending on filter medium). Each individual instrument is subjected to the same procedures before shipment to confirm that the generally-applicable attenuation coefficient is accurate for that instrument.

14.1.3 The long half-life of carbon-14 minimizes the need for recalibrating and replacing the beta source. During operation, the instrument continually runs internal diagnostic checks to ensure the proper operation of the source/detector system. The foil calibration feature, available on new or kit-modified units, may be used by the operator to check the calibration of the instrument and, if necessary, to change the calibration constant (attenuation coefficient), using a calibration foil provided by the manufacturer. Follow the instructions for this feature in the Operator's Manual or Manual Addendum.

14.2 Flow Rate

14.2.1 As discussed in Section 7.9, flow control for the instrument is achieved using a critical flow system. Each instrument is calibrated by the manufacturer to determine the instrument-specific flow coefficient that is used in internal calculations to determine the flow rate.

14.2.2 The manufacturer recommends no periodic recalibration by the user. However, a quarterly field audit is required by EPA for any instrument operating as an equivalent method for PM₁₀. The audit procedure is presented in the following section.

14.3 Single-Point External Flow Rate Audit Procedure Using a Flow Transfer Standard

14.3.1 Background. This section describes an external means of auditing the volumetric flow rate of the instrument. An NIST-traceable primary standard is used to calibrate a transfer standard which, in turn, is used to verify the calibration of the instrument's CFD.

Several commercially available transfer standards can be used in this audit procedure. Table 3 lists recommended transfer standards, their applicable flow ranges, references for transfer calibration procedures, and necessary equipment to perform calibrations. (This table has been adopted from the EPA Quality Assurance Handbook for air pollution measurement systems [EPA 600/4-77-027A].) Because the design flow rate for the PM₁₀ inlet is 16.7 L/min, the transfer standard should be calibrated in the flow rate range of approximately 15 to 20 L/min. The transfer standard should not cause a pressure drop of more than 4.0" of water.

After selecting a transfer standard, use a leak-tight adapter to connect the transfer standard to the instrument inlet tube as depicted in Figure 8. The adapter may be fabricated by a third party, purchased commercially, or requested from the manufacturer.

Normally, a station log book or audit data sheet is used to document audit information. This information normally includes, but is not limited to, an identification of the transfer standard, its serial number, traceability documentation for the audit information, and the ambient temperature and pressure as well as the actual audit data collected during audit procedures.

14.3.2 Audit Procedure.

14.3.2.1 Remove the PM₁₀ inlet from the instrument. Install the adapter, referring to Figure 8 for details. Connect the flow transfer standard, as depicted in Figure 9, using suitable tubing.

14.3.2.2 Press the key on the keypad titled "FLOWRATE". (This command will establish necessary audit conditions, such as advancing the tape to a new/unused area of the medium.) Be sure that the filter tape is fully loaded and the sampling module is in the closed position.

14.3.2.3 Allow time for the flow transfer standard to equilibrate, which requires operating the system for approximately 5 min. During this operation, the inlet of the transfer standard is open to ambient air, and the outlet of the transfer standard is connected via the adapter to the inlet tube of the instrument.

14.3.2.4 Record all pertinent parameters required to make calculations from the flow transfer standard's previous calibration. These parameters may include, but are not limited to, ambient pressure and temperature and transfer standard readings such as volts, pressure drop, timings or revolutions, etc. During this time the instrument's computer will calculate, and the LCD will display, a continuing series of flow rate values based upon measured flow conditions. Time-averaged flow rate values will be produced and updated every 2 min. These values allow the operator to make comparisons between readings of the flow transfer standard and the values output to the LCD by the computer.

[Note: New or modified instruments displays flow rates in either standard or actual cm³/min. Always be sure that the instrument and transfer standard flow rates are in the same terms (actual or standard) before comparing them.]

14.3.2.5 Depending upon the purpose or nature of the audit, the flow rate values displayed on the LCD should agree within a specified percentage of the flow rate transfer standard values. For purposes of flow rate audits required by the EPA, all values displayed on the LCD should agree within $\pm 7\%$ of the flow rate transfer standard values. If not, check all calculations to ensure that the flow rates are in the same terms (actual or standard volumes). These values need not necessarily be the design flow rate value of 18.9 L/min.

14.3.2.6 If the flow transfer standard and the instrument do not agree within $\pm 7\%$, refer to Section 9.4.1 (Trouble Shooting). Fill out the detailed trouble-shooting check list in the Addendum to the manufacturer's technical manual (2). In particular, items 4-10 relate directly to flow rate verification. Report these results to Thermo for further information.

14.3.2.7 To compare the design flow rate of 18.9 L/min to the actual flow rate displayed on the LCD, remove both the external transfer standard and the external transfer standard adapter. Replace the PM₁₀ inlet onto the inlet tube. Allow approximately 1-2 min for the flow to equilibrate; observe the series of flow rate values displayed on the LCD. Make sure that the instrument is reading the flow rate in *actual* volumetric units, and apply a percentage correction determined in Section 14.3.2.5. These values should be within $\pm 10\%$ of the design flow rate value of 16.7 L/min; if not, refer to Section 14.3.2.6.

14.4 Mass Determination Audit

As noted in Section 14.1.3, the foil calibration feature, available on new or kit-modified units, may be used by the operator to check the calibration of the instrument and, if necessary, to change the calibration constant (attenuation coefficient), using a calibration foil provided by the manufacturer. Follow the instructions for this feature in the Operator's Manual of Manual Addendum.

14.5 Leak Checking

The instrument is assembled and leak checked before it is shipped to the user. No routine definitive leak checking procedures are conducted thereafter. The manufacturer does not recommend positive or negative pressure leak checking because this activity could rupture the gaskets in the sampling module. To check for leaks, examine the vacuum tubing and verify that all connections at the inlet, inlet tube, and vacuum tubing are secure. Examine the filter tape to verify that all spots where PM has been collected are sharply-defined circles. Poorly-defined sample spots indicate leaking sampling module gaskets.

15. Safety

This instrument uses a radioactive source to measure PM₁₀. The Nuclear Regulatory Commission does not require the user of this low-energy, beta-emitting source to be licensed (however, Thermo is so licensed). The beta source is sealed at the factory and should never be opened or tampered with. The entire instrument should be returned to Thermo for service or disposal of the beta source.

16. Performance Criteria and Quality Assurance (QA)

Required quality assurance measures and guidance concerning performance criteria that should be activated within each laboratory are summarized and provided in the following section.

16.1 Standard Operating Procedures (SOPs)

16.1.1 SOPs should be generated by the users to describe and document the following activities in their laboratory:

- Assembly, calibration, leak check, and operation of the specific sampling system and equipment used;
- Preparation, storage, shipment, and handling of the sampler system;
- Purchase, certification, and transport of standard reference materials; and
- All aspects of data recording and processing, including lists of computer hardware and software used.

16.1.2 Specific instructions should be provided in the SOPs and should be readily available to and understood by the personnel conducting the monitoring work.

16.2 QA Program

The user should develop, implement, and maintain a quality assurance program to ensure that the sampling system is operating properly and collecting accurate data. Established calibration, operation, and maintenance procedures should be conducted on a regularly scheduled basis and should be part of the quality assurance program. Calibration verification procedures provided in Section 14, operation procedures in Section 10, and the manufacturer's instruction manual should be followed and included in the QA program. Additional QA measures (e.g., trouble shooting) as well as further guidance in maintaining the sampling system are provided by the manufacturer. For detailed guidance in setting up a quality assurance program, the user is referred to the *Code of Federal Regulations* (3) and the *U. S. EPA Handbook on Quality Assurance* (4).

17. References

1. Equivalent Method Designation: PM₁₀ Beta Gauge Automated Particle Sampler, *Federal Register*, Vol. 56, No. 43, March 5, 1991, pp. 9216-9217.
2. Wedding, J. B., and Weigland, M.A., *Wedding & Associates' PM₁₀ (or TSP) Beta Gauge Automated Particle Sampler Operations and Maintenance Manual*. Fort Collins, CO, February 1991.
3. 40 CFR, Part 58, Appendices A and B.
4. *Quality Assurance Handbook for Air Pollution Measurement Systems, Volume II--Ambient Air Specific Methods*, (Interim Edition), EPA 600/R-94/038b.

5. U. S. Environmental Protection Agency, *Quality Assurance Handbook for Air Pollution Measurement Systems, Volume I: A Field Guide for Environmental Quality Assurance*, EPA-600/R-94/038a.

TABLE 1. EXAMPLE OF MINIMUM SAMPLER SITING CRITERIA

Scale	Height above ground, meters	Distance from supporting structure, meters		Other spacing criteria
		Vertical	Horizontal ^a	
Micro	2 to 7	> 2	> 2	1. Should be > 20 meters from trees. 2. Distance from sampler to obstacle, such as buildings, must be twice the height that the obstacle protrudes above the sampler. ^a 3. Must have unrestricted airflow 270 degrees around the sampler inlet. 4. No furnace or incineration flues should be nearby. ^b 5. Spacing from roads varies with traffic (see 40 CFR 58, Appendix E). 6. Sampler inlet is at least 2 m but not greater than 4 m from any collocated PM ₁₀ sampler (see 40 CFR 58, Appendix E).
Middle, neighborhood, urban, and regional scale	2 to 15	> 2	> 2	

^aWhen inlet is located on rooftop, this separation distance is in reference to walls, parapets, or penthouses located on the roof.

^bDistance depends on the height of furnace or incineration flues, type of fuel or waste burned, and quality of fuel (sulfur, ash, or lead content). This is to avoid undue influences from minor pollutant sources. As a precautionary measure, the sampler should be placed at least 5 meters from the furnace or incinerator flue.

TABLE 2. SUMMARY OF KEYPAD CONTROL KEYS

ROW	COLUMN	LETTERING ON KEY	DESCRIPTION
1	1	PROGRAM SAMPLING SCHEDULE	allows input of the desired start date and start time in which the sampling cycle will begin
1	2	MODULE UP/DN	moves the sampling module one full cycle (i.e., move down and back up)
1	3	TEMP/PRESS	displays the cabinet temperature and pressure readings on the LCD
1	4	PARALLEL PRINTER ON/OFF	output directed to parallel printer (telemetry output still active)
1	5	SETUP	allows viewing and resetting of the battery-backed real-time clock
2	1	BEGIN SAMPLING	starts or begins the sampling cycle
2	2	COMP. UP/DN	moves the compression rollers one full cycle (i.e., move up and back down)
2	3	BETA COUNT	determines if beta particles are being counted acceptably or unacceptably
2	4	RS-232 PRINTER ON/OFF	output directed to RS-232/serial printer (telemetry output still active)
2	5	STATUS	reads and displays the status of the external I/O devices (i.e., parallel printer, serial printer, RS-232 communications)
3	1	LOAD TAPE	refers user to manual, opens mechanical systems
3	2	TRANS. LEFT/RIGHT	moves the translation assembly one full cycle (i.e., move right and back left)
3	3	FLOW RATE	displays the sampler flow rate reading on the LCD
3	4	RS-232 COMM. ON/OFF	allows setting the RS-232 baud rate for off-site communications
3	5	TROUBLE SHOOT	executes a series of analog, digital, and mechanical diagnostics and displays the results on the LCD
4	1	ADVANCE TAPE	advances the filter media one location
4	2	VACUUM PUMP ON/OFF	tests the vacuum pump
7	1	C	allows input of the calibration constant in battery-backed RAM if lost through battery failure
8	1	D	allows setting the maximum mass concentration limit in battery-backed RAM
8	3	RESET	resets the computer
5	1	A	interrupts sampling at the conclusion of the current sampling/measurement cycle (key enabled only while in sampling mode)
6	2	B	interrupts sampling immediately (key enabled only while in sampling mode)

TABLE 3. EXAMPLE OF RECOMMENDED STANDARDS AND ASSOCIATED EQUIPMENT FOR FLOW RATE AUDITS

Transfer standard ^a	Optimum flow range Q _a	Equipment	Comments	Calibration equation ^{b,c}	Calibration of transfer standard reference
LFE (laminar flow element)	15.0-20.0 L/min	LFE Thermometer/barometer ^d Manometer ^e , Filters, Adapter	Should have filtered air entering LFE. Subject to fluctuations due to temperature changes. Manometer must be used in its temperature range. Must equilibrate.	(^a H ₂ O)(CF) = Q _{std}	U. S. Environmental Protection Agency Procedures for Calibrating a Laminar Flow Element (LFE) against an NBS Calibrated LFE: Standard Operating Procedures EMSL/RTP SOP-QAD-003, November 1991
MFM (mass flow meter)	15.0-20.0 L/min	MFM Thermometer/barometer ^d Filters, Adapter	Recommended LCD display for outdoor use. Must equilibrate to ambient conditions.	(Volts)(CF) = Q _{std}	Quality Assurance Handbook for Air Pollution Measurement Systems - Vol. II Ambient Air Specific Methods, Section 21, EPA 600/4-77-027A, May 1977.
DGM L/rev (dry gas meter)	15.0-20.0 L/min	DGM Thermometer/barometer ^d Stopwatch, ^f Filters, Adapter	Should time through five revolutions. Repeat each timing 3 times.	$\frac{\text{Volume}}{\text{time}}(\text{CF}) = Q_{\text{std}}$	Quality Assurance Handbook for Air Pollution Measurement Systems - Vol. II Ambient Air Specific Methods, Section 3.3 EPA 600/4-77-027B, August 1977.
Orifice	15.0-20.0 L/min	Orifice Thermometer/barometer, ^d Manometer, ^e Filters, Adapter	Good only in range ^a P < 8 in.	$m \left[\text{H}_2\text{O} \frac{P_a}{T_a} \right]^{1/2} \% b = Q_{\text{std}}$	Quality Assurance Handbook for Air Pollution Measurement Systems - Vol. II Ambient Air Specific Methods, Section 2.2 EPA 600/4-77-027A. May 1977.

^aTransfer standard should not cause more than 4.0" of H₂O flow resistance to the sampler flow.

^bTraceable and referenced to EPA standard conditions:

$$Q_a = Q_{\text{std}} \left[\frac{T_a}{P_a} \right] \left[\frac{P_{\text{std}}}{T_{\text{std}}} \right]$$

^cCalibration equations for determining flow rates may vary from those presented due to the transfer standard calibration relationship. CF = correction factor.

^dThermometer capable of measuring temperature to the nearest +1C. Barometer capable of accurately measuring barometric pressure to the nearest +1 mm Hg.

^eThe design or size of the LFE or orifice will determine the manometer range necessary and the resolution. The manometer resolution must be capable of detecting a flow change of 1% and represent a flow resistance less than 4.0" H₂O.

^fStopwatch or timer capable of accurately measuring time intervals of 30 s to several minutes to nearest 0.1 s.

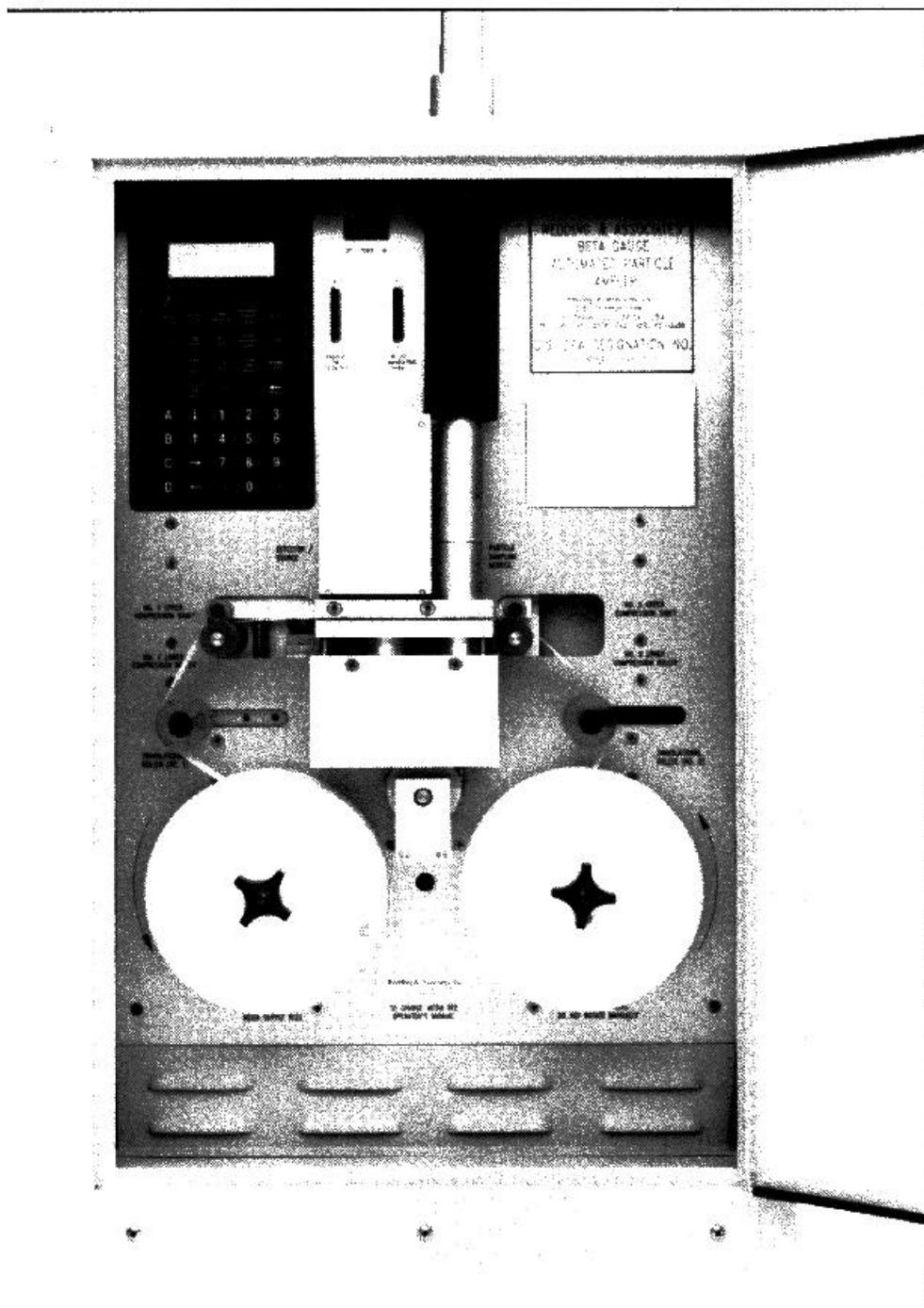


Figure 1. The Thermo beta gauge main particle sampling cabinet.

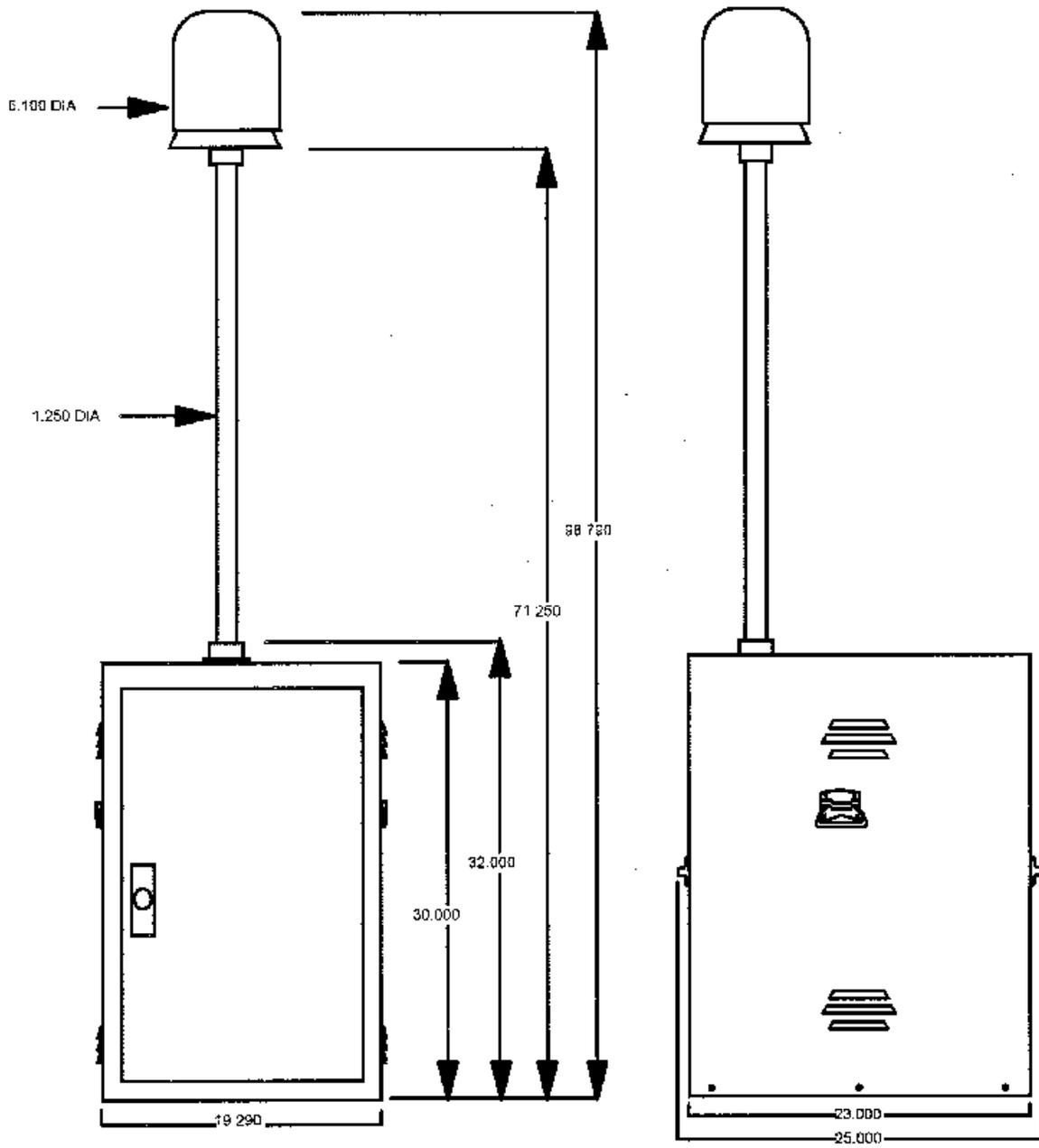


Figure 2. Main cabinet with PM₁₀ inlet and inlet tube.

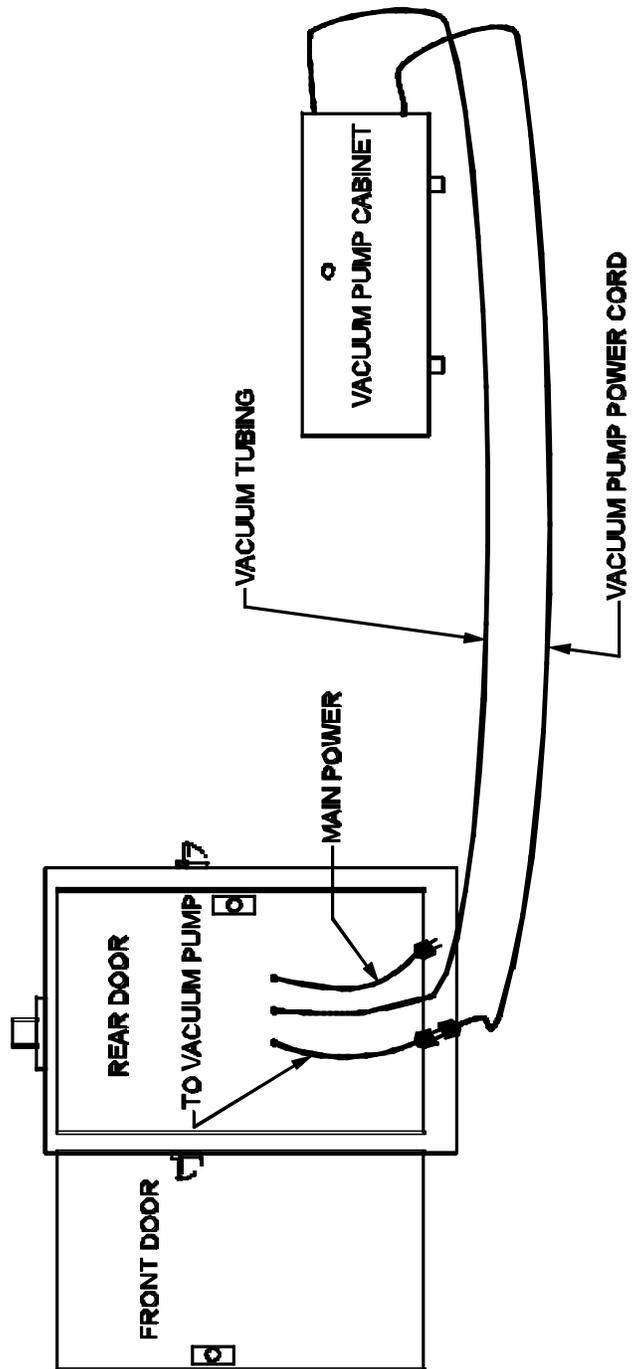


Figure 3. Rear of Main Cabinet with Connections to Vacuum Pump Cabinet.

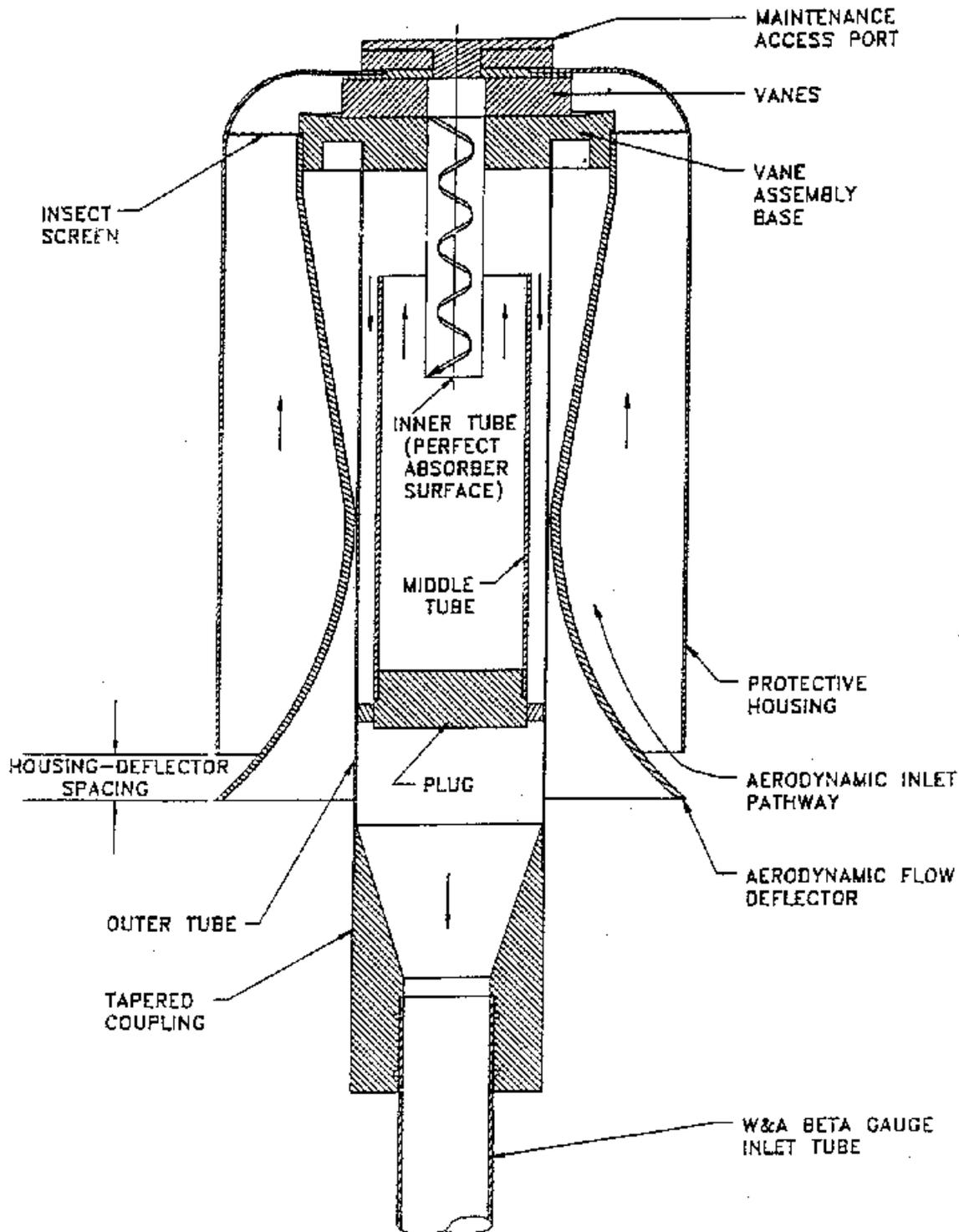


Figure 4. Thermo PM₁₀ inlet.

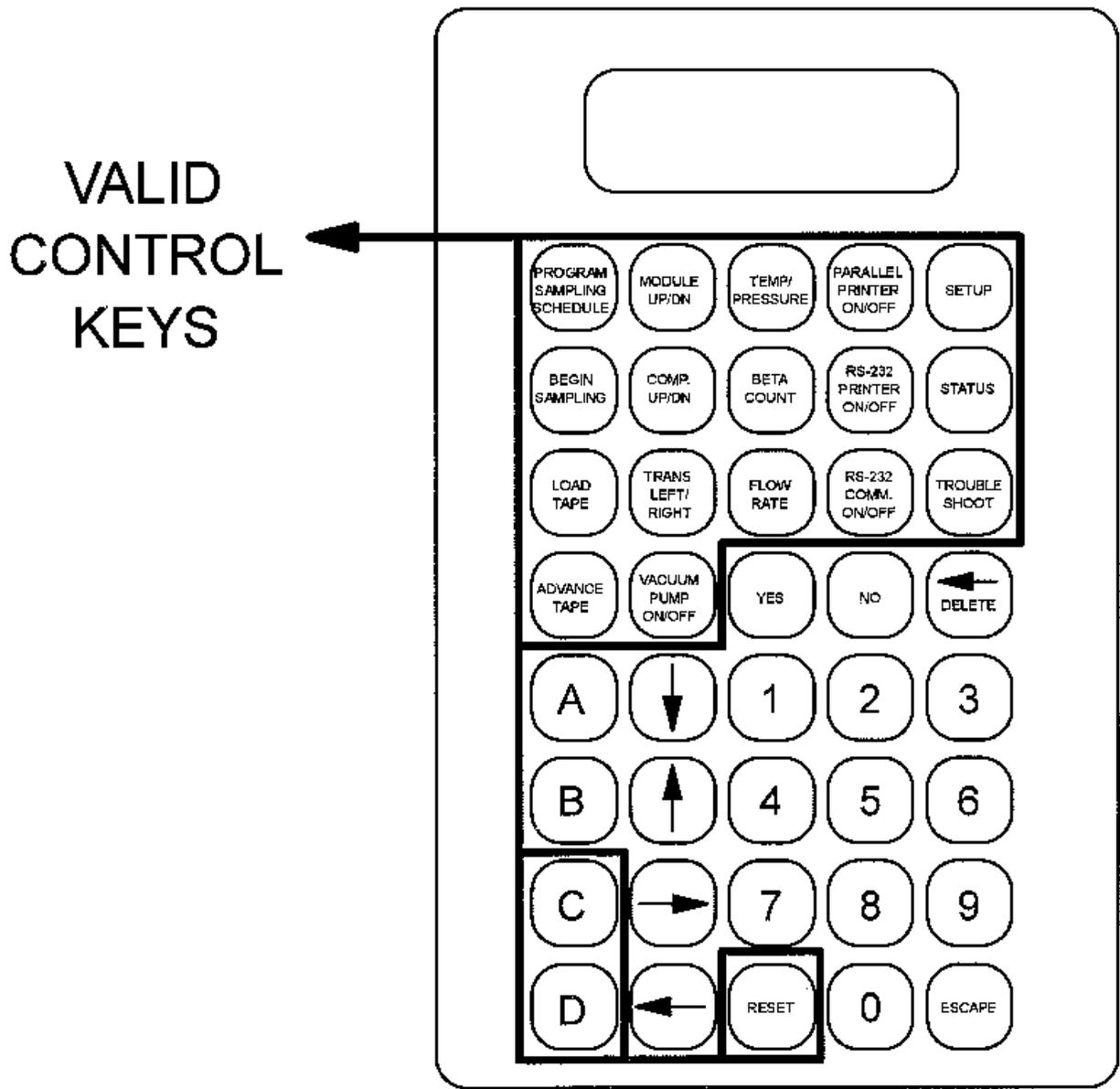


Figure 5. Thermo PM₁₀ instrument keypad.

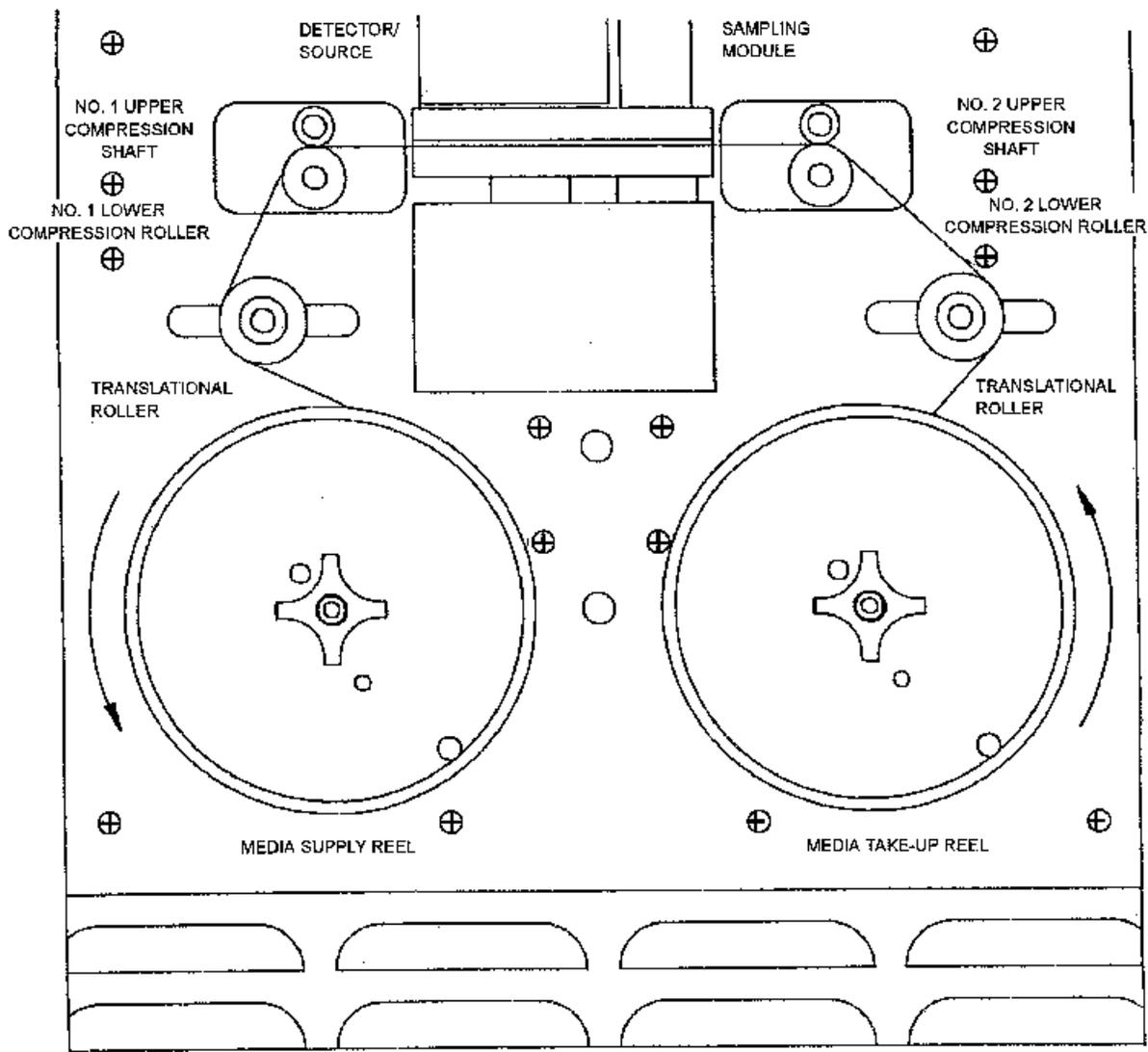


Figure 6. Filter tape drive system.

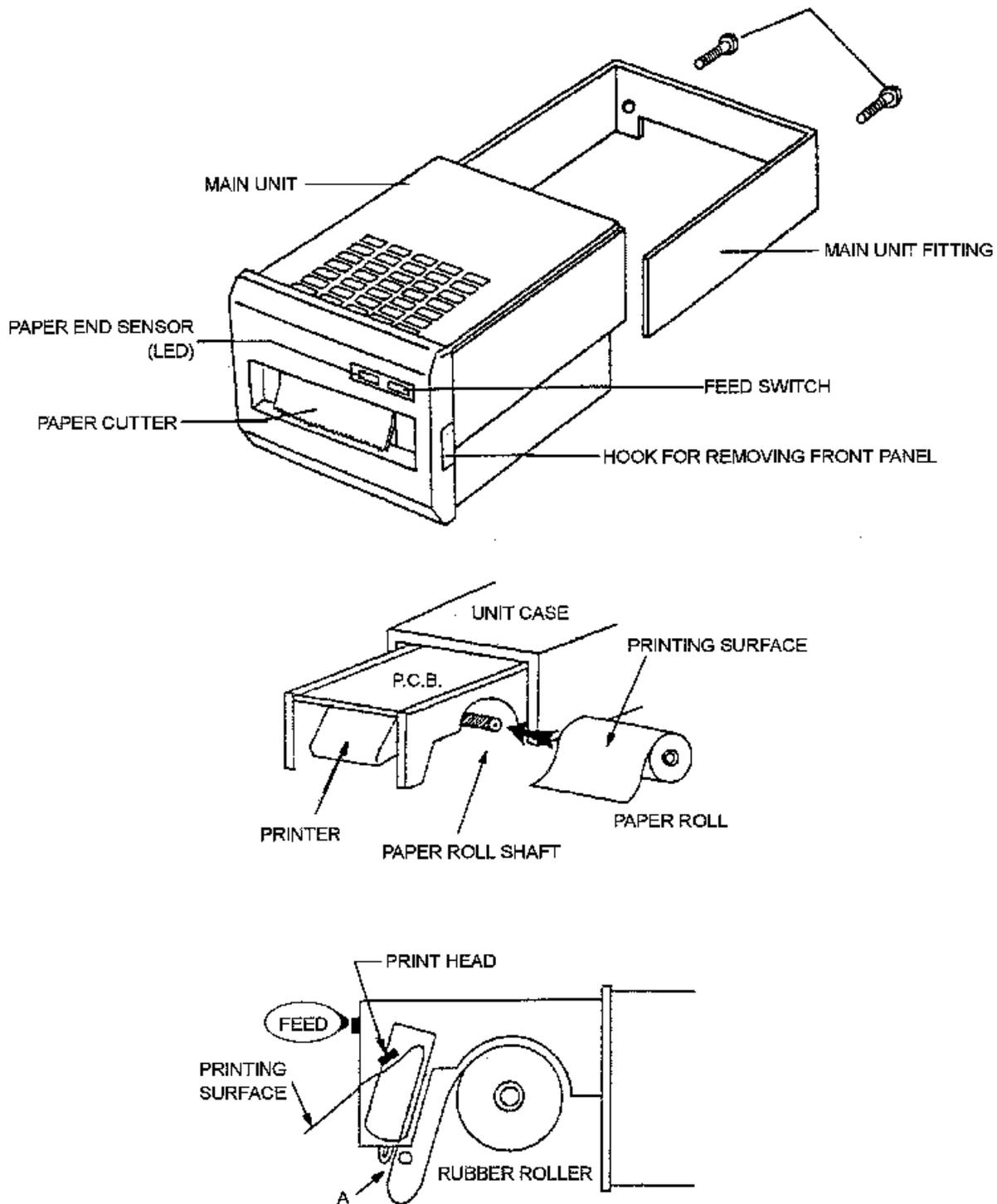


Figure 7. Replacing paper in the parallel printer.

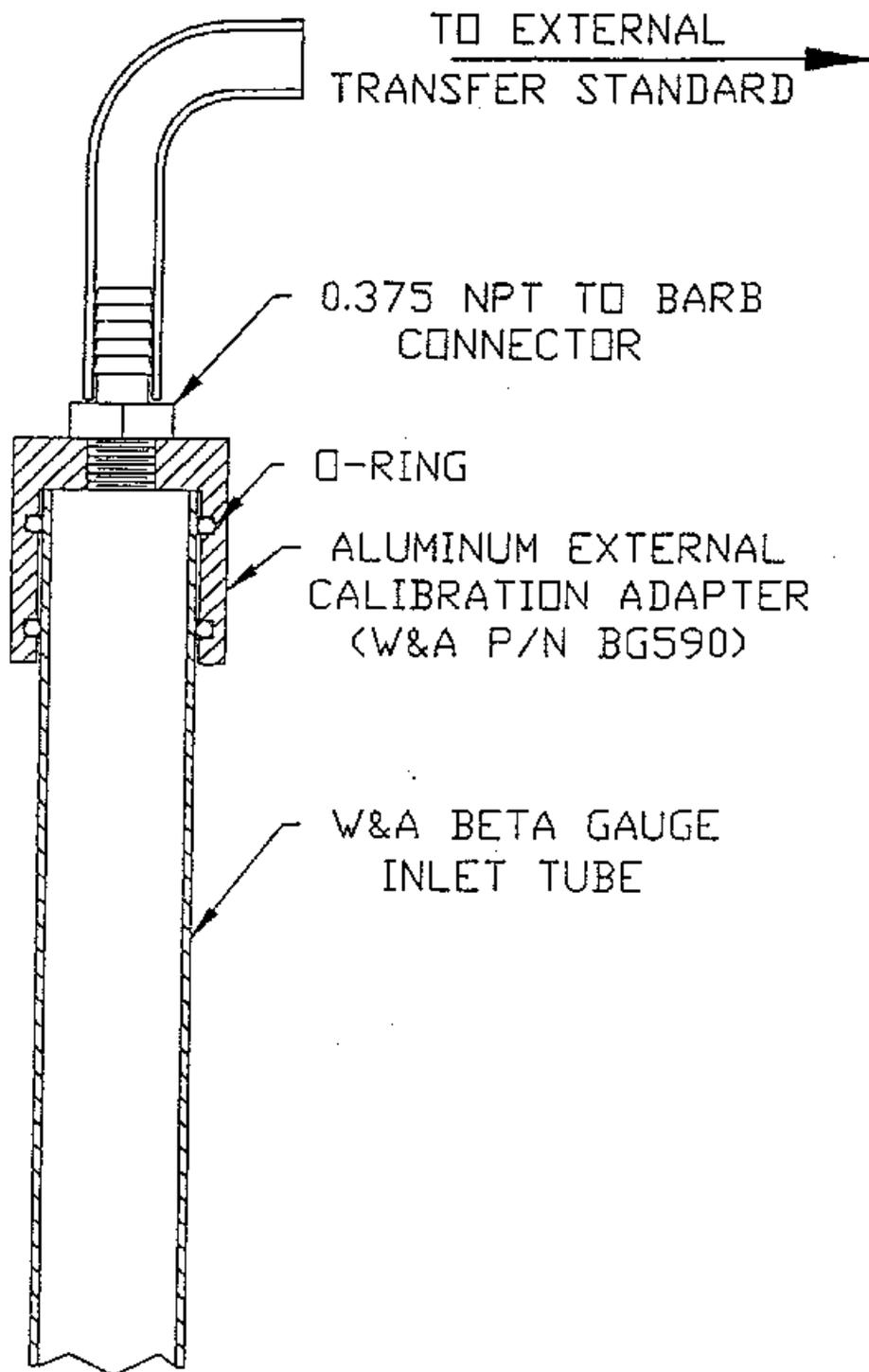


Figure 8. Adapter for external flow transfer standard.

TABLE 3. EXAMPLE OF RECOMMENDED STANDARDS AND ASSOCIATED EQUIPMENT FOR FLOW RATE AUDITS

Transfer standard ^a	Optimum flow range Q _a	Equipment	Comments	Calibration equation ^{b,c}	Calibration of transfer standard reference
LFE (laminar flow element)	15.0-20.0 L/min	LFE Thermometer/barometer ^d Manometer ^e , Filters, Adapter	Should have filtered air entering LFE. Subject to fluctuations due to temperature changes. Manometer must be used in its temperature range. Must equilibrate.	(^a H ₂ O)(CF) = Q _{std}	U. S. Environmental Protection Agency Procedures for Calibrating a Laminar Flow Element (LFE) against an NBS Calibrated LFE: Standard Operating Procedures EMSL/RTP SOP-QAD-003, November 1991
MFM (mass flow meter)	15.0-20.0 L/min	MFM Thermometer/barometer ^d Filters, Adapter	Recommended LCD display for outdoor use. Must equilibrate to ambient conditions.	(Volts)(CF) = Q _{std}	Quality Assurance Handbook for Air Pollution Measurement Systems - Vol. II Ambient Air Specific Methods, Section 21, EPA 600/4-77-027A, May 1977.
DGM L/rev (dry gas meter)	15.0-20.0 L/min	DGM Thermometer/barometer ^d Stopwatch, ^f Filters, Adapter	Should time through five revolutions. Repeat each timing 3 times.	$\frac{\text{Volume}}{\text{time}}(\text{CF}) \cdot Q_{\text{std}}$	Quality Assurance Handbook for Air Pollution Measurement Systems - Vol. II Ambient Air Specific Methods, Section 3.3 EPA 600/4-77-027B, August 1977.
Orifice	15.0-20.0 L/min	Orifice Thermometer/barometer, ^d Manometer, ^e Filters, Adapter	Good only in range ^a P < 8 in.	$m \left[\text{H}_2\text{O} \frac{P_a}{T_a} \right]^{1/2} \% b \cdot Q_{\text{std}}$	Quality Assurance Handbook for Air Pollution Measurement Systems - Vol. II Ambient Air Specific Methods, Section 2.2 EPA 600/4-77-027A. May 1977.

^aTransfer standard should not cause more than 4.0" of H₂O flow resistance to the sampler flow.

^bTraceable and referenced to EPA standard conditions:

$$Q_a \cdot Q_{\text{std}} \left[\frac{T_a}{P_a} \right] \left[\frac{P_{\text{std}}}{T_{\text{std}}} \right]$$

^cCalibration equations for determining flow rates may vary from those presented due to the transfer standard calibration relationship. CF = correction factor.

^dThermometer capable of measuring temperature to the nearest +1°C. Barometer capable of accurately measuring barometric pressure to the nearest +1 mm Hg.

^eThe design or size of the LFE or orifice will determine the manometer range necessary and the resolution. The manometer resolution must be capable of detecting a flow change of 1% and represent a flow resistance less than 4.0" H₂O.

^fStopwatch or timer capable of accurately measuring time intervals of 30 s to several minutes to nearest 0.1 s.